ADVANCES IN BIOMAGNETISM

Edited by

Samuel J. Williamson

Manfried Hoke

Gerhard Stroink

Makoto Kotani

ADVANCES IN BIOMAGNETISM

Edited by

Samuel J. Williamson
New York University
New York, New York

Manfried Hoke
Westfälische Wilhelms-Universität Münster
Münster, Federal Republic of Germany

Gerhard Stroink
Dalhousie University
Halifax, Nova Scotia, Canada

and

Makoto Kotani
Tokyo Denki University
Tokyo, Japan

PLENUM PRESS • NEW YORK AND LONDON

Library of Congress Cataloging-in-Publication Data

International Conference on Biomagnetism (7th : 1989 : New York, N.Y.)
Advances in biomagnetism / edited by Samuel J. Williamson ... [et al.].
p. cm.
"Proceedings of the Seventh International Conference on Biomagnetism, held August 1989, in New York, New York"--T.p. verso.
Includes bibliographical references.
ISBN 0-306-43483-0
1. Biomagnetism--Congresses. I. Williamson, Samuel J.
II. Title.
QP82.2.M3I54 1989
612'.0142--dc20
89-49359
CIP

Proceedings of the Seventh International Conference on Biomagnetism, held August 13–18, 1989, in New York, New York

© 1989 Plenum Press, New York
A Division of Plenum Publishing Corporation
233 Spring Street, New York, N.Y. 10013

All rights reserved

No part of this book may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, microfilming, recording, or otherwise, without written permission from the Publisher

Printed in the United States of America

CONFERENCE ORGANIZATION

Co-Chairmen

Lloyd Kaufman
Department of Psychology
New York University
New York City, USA

Samuel J. Williamson
Department of Physics
New York University
New York City, USA

Local Committee

Douglas Brenner
Sarah Curtis
Yael Cycowicz
Jinchu Huang
Gladys Klemic
Yoshio Okada
Urs Ribari
Carlo Salustri
Barry Schwartz
Juna Suk
Jia-Zhu Wang

Program Committee

AMERICAN SECTION

Chairman:
Prof. Gerhard Stroink
Department of Physics
Dalhousie University
Halifax, Canada

Prof. Daniel Barth
Department of Neurology
UCLA School of Medicine
Los Angeles, USA

Prof. Paulo Costa Ribeiro
Departamento da Fisica
Pontifica Universidade Catolica
Rio de Janeiro, Brazil

ASIAN SECTION

Chairman:
Prof. Makoto Kotani
Department of Electronics
Tokyo Denki University
Tokyo, Japan

Dr. Hisashi Kado
Acoustics Section
Natl. Electrotechnical Laboratory
Tsukuba, Japan

Prof. Hiroyoshi Mori
School of Medicine
The University of Tokushima
Tokushima, Japan

EUROPEAN SECTION

Chairman:
Univ.-Prof. Dr. med. Manfried Hoke
Inst. für Experimentelle Audiologie
Westfälische Wilhelms-Universität
Münster, FRG

Prof. Riccardo Fenici
1st Di Clin. Medica Generale
Università Cattolica del Sacro Cuore
Rome, Italy

Dr. Maria J. Peters
Department of Applied Physics
University of Twente
Enschede, The Netherlands

Dr. Victor Vvedensky
Kurchatov Institute of Atomic Energy
Moscow, USSR

Advisory Committee

Chairman:
Prof. Kazuhiko Atsumi
Institute of Medical Electronics
University of Tokyo
Tokyo, Japan

Dr. David Cohen
F. Bitter National Magnet Lab.
M.I.T.
Cambridge, USA

Dr. Sergio Erné
Physikal. Technische Bundesanstalt
Institut Berlin
Berlin, FRG

Prof. Toivo E. Katila
Department of Technical Physics
Helsinki University of Technology
Espoo, Finland

Prof. Gian Luca Romani
Ist. di Elettronica dello Stato Solido
CNR
Rome, Italy

Prof. Shoogo Ueno
Department of Electronics
Kyushu University
Fukuoka, Japan

Prof. Harold Weinberg
Brain Behavior Laboratory
Simon Fraser University
Burnaby, Canada

Prof. John P. Wikswo, Jr.
Dept. of Physics and Astronomy
Vanderbilt University
Nashville, USA

Prof. Samuel J. Williamson
Department of Physics
New York University
New York, USA

Sponsors

Air Force Office of Scientific Research (USA)

Biomagnetic Technologies, Inc.

Office of Naval Research (USA)

Siemens AG

Yokogawa Medical Systems/GE

New York University

A Topical Conference of the American Physical Society

PREFACE

This volume celebrates the 20th anniversary of the first application of superconducting magnetic field sensors to biomagnetism by providing a comprehensive survey of advances in biomagnetic research worldwide. "Biomagnetism" is the investigation of biological processes as reflected by accompanying magnetic fields. It embraces basic and clinical research, as well as applications in medicine and occupational health. The contents of this book are the proceedings of the 7th International Conference on Biomagnetism, held from August 13 through 18, 1989, at New York University – in the heart of the Greenwich Village area of Manhattan. Topics include studies of the brain, heart, liver, lungs, muscle, tissue *in vitro*, advances in instrumentation, development of theory, and related topics.

Interdisciplinary in emphasis, this presentation begins with a set of tutorials by five outstanding professors: John Wikswo, Toivo Katila, Gian Luca Romani, Gerhard Stroink, and Stephen Swithenby. These tutorials were especially prepared to serve as an introduction for readers who are relatively new to the subject. They are followed by three presentations that mark the 20th anniversary of the first application of a SQUID sensor to biomagnetism (the acronyn SQUID is shorthand for *s*uperconducting *qu*antum *i*nterference *d*evice). Articles by James Zimmerman and Edgar Edelsack look back to the catalytic process that affected a marriage between Zimmerman's SQUID and David Cohen's magnetically shielded room. The accomplishment of these three pioneers in recording the extremely weak magnetic field of the heart with great clarity stimulated international interest in biomagnetic phenomena. Roger Koch follows this retrospective with his own prospective by describing recent dramatic advances in the development of SQUIDs that work at much higher temperatures than conventional ones. With a "high T_c SQUID" liquid helium can be replaced as a coolant by a small-scale refrigerator that cycles gaseous nitrogen. Some benefits are small size, simplicity in refrigeration, versatile configurations for sensor arrays, and reduced cost. Recent technological achievements provide substance to the prediction that the next 20 years will yield manifold advances in biomagnetic applications, perhaps even the introduction of a "personal SQUID" whose versatility would be analogous to the personal computer's.

The major emphasis of this volume are 11 invited and 172 contributed articles, which are grouped according to specialized topics. Three major advances are revealed. Most dramatic is the unveiling of newly developed large arrays of magnetic sensors – some commercial and others in research laboratories – which can sample simultaneously a field pattern from many more positions than was previously possible. They substantially speed data acquisition and provide greatly enhanced recording quality. The second advance is in techniques for deducing information about the distributed nature of underlying current patterns. To date, interest has been nearly exclusively directed toward a single localized patch of activity, for example in the heart or brain. Going hand in hand with these developments is the third advancement: graphics that begin to portray the time evolution of widespread patterns of electrical current. Thus the interplay is revealed of distributed biological activity, as in several separate regions of the brain. Emphasis in biomagnetism is advancing from the study of single, isolated events to an appreciation for the ensemble of activity.

A conference for four hundred participants can be a success only by virtue of dedicated contributions from many individuals. Selection of invited presentations and supervision of referees for all of the presentations was the responsibility of the Program Committee. Marc Hoke, Makoto Kotani, and Gerhard Stroink were Chairmen of the European, Asian, and American Sections, respectively, and are Co-Editors of this volume. They and members of the Program Committee ensured that contributions were scrutinized by at least two peer reviewers, thus setting a high standard for acceptance. Members of the Program Committee, Advisory Committee, and Organizing Committee are listed after this preface. Jia-Zhu Wang deserves special acknowledgement for helping with the editorial preparation of this volume. We wish to thank as well our many colleagues at New York University, in particular Robert Kivetz and Michelle Gaillard for invaluable administrative help and the assistance of their staffs with local arrangements; Sek Lien for his talented contributions to design and graphics of conference publications and John Yadrick for overall guidance; and especially the Neuromagnetism Group at NYU, which put heart and soul into a great effort to make this conference the acknowledged success it was.

We as Co-Chairmen wish to thank especially the six Sponsors of the conference, whose contributions were essential for attaining the highest quality for all the presentations that are set forth in this book.

Samuel J. Williamson
Lloyd Kaufman

Co-Chairmen

CONTENTS

Tutorials

Biomagnetic Sources and Their Models (*invited*) 1
J.P. Wikswo, Jr.

Principles and Applications of SQUID Sensors (*invited*) 19
T.E. Katila

Fundamentals of Neuromagnetism (*invited*) 33
G.L. Romani

Principles of Cardiomagnetism (*invited*) 47
G. Stroink

Biomagnetic Studies of Organs other than the Heart and Brain (*invited*) 57
S.J. Swithenby

20th Anniversary of the SQUID's Introduction

Evaluation of the SQUID and its Use in Biomagnetic Research (*invited*) 67
J.E. Zimmerman

A Vicennial View of SQUID Magnetocardiography (*invited*) 73
E. Edelsack

Present Status and Future of DC SQUIDs made from High T_c Superconductors (*invited*) 81
R.H. Koch, W.J. Gallagher, V. Foglietti, B. Oh, R.B. Laibowitz, G. Koren A. Gupta, and W.Y. Lee

Neuromagnetism: Auditory Evoked Responses

Activation of the Human Auditory Cortex by Various Sound Sequences: Neuromagnetic Studies (*invited*) 87
R. Hari

Selective Averaging in Auditory Evoked Magnetic Field Experiments 93
K.B. Mikkelsen, K. Saermark, J. Lebech, C.K. Bak, and E. Basar

Frequency-Specific Sources of the Auditory N19-P30-P50 Response Detected by a Multiple Source Analysis of Evoked Magnetic Fields and Potentials 97
M. Scherg, R. Hari, and M. Hämäläinen

Replicability for Localization of the P1, N1, and P2 Components of the Auditory Evoked Response in an Unselected Group of Subjects 101
S. Baumann, R. Rogers and A. Papanicolaou, and C. Saydjari

Nonstationary Dynamics of Sequential Magnetic Dipole Source Changes Associated with N100 Auditory Evoked Responses 105
R.L. Rogers, A.C. Papanicolaou, S. Baumann, C. Saydjari, and H.M. Eisenberg

Event Related Potentials and Fields Evoked by Auditory Stimuli: Effects of Interstimulus Interval and Selective Attention 109
S. Kuriki, F. Takeuchi, and M. Murase

Neural Mechanisms of Selective Auditory Attention 113
D. Arthur, S. Hillyard, E. Flynn, and A. Schmidt

Neuromagnetic Responses to Infrequent Changes in Periodicity Pitch 117
S.T. Lu, R. Hari, and M. Sams

Paired Tone Presentation Enhances Responses of Human Auditory Cortex to Rare Frequency Changes 121
J. Rif, R. Hari, and J. Tiihonen

Neuromagnetic Responses of the Human Auditory Cortex to Different Types of Deviant Stimuli 125
M. Sams, E. Kaukoranta, M. Hämäläinen, and R. Näätänen

Specificity of Neuromagnetic Responses in the Human Auditory Cortex to Consonants of Monosyllable Speech Sounds 129
S. Kuriki, M. Murase, and F. Takeuchi

Neuromagnetism: Somatomotor and Nerve Activity

Short-Latency Somatosensory Evoked Magnetic Fields Recorded over the Brachial Plexus and Cervical Spine in Man 133
G. Curio, S.N. Erné, J. Sandforth, J. Scheer, R. Stehr, and L. Trahms

Intraoperative Recording of the Magnetic Field of a Human Nerve 137
J.P. Wikswo, W.P. Henry, R.N. Friedman, A.W. Kilroy, R.S. Wijesinghe, J.M. van Egeraat, and M.A. Milek

A Comparative Study of Compound Action Potentials and Currents 141
K.W. Kim, D.J. Engle, and R.J. Sclabassi

Estimation of Both Conduction Velocities and the Number of Firing Nerve Fibers from Magnetic Fields Outside a Volume Conductor 145
S. Ueno and S. Suzuki

Source Localisation from Somatosensory Neuromagnetic Data 149
R.J-M. Grognard and A.D. Seagar

Short Latency Median Nerve Somatosensory Evoked Magnetic Fields and Electrical Potentials 153
C.L. Lim, C. Rennie, C. Yiannikas, E. Gordon, G.J. Sloggett, R.J-M. Grognard, and A.D. Seagar

On the Frontal Components of Somatosensory Scalp Responses to Median Nerve Stimulation: Neuromagnetic Demonstration of an Anterior, Midline Generator 157
P.M. Rossini, L. Narici, V. Pizzella, G.L. Romani, and R. Traversa

Spatiotemporal Modeling of Somatosensory Evoked Magnetic Fields 161
C. Baumgartner, D.S. Barth, and W.W. Sutherling

Magnetic Localization of Somatically Evoked Responses in the Human Brain 165
J. Suk, J. Cappell, U. Ribary, T. Yamamoto, and R.R. Llinás

Evoked and Spontaneous Magnetic Activity of the Human Somatosensory Cortex 169
J. Tiihonen, R. Hari, M. Kajola, and M. Hämäläinen

ECD Tracing for Middle Latencies of Neuromagnetic Responses to Right Tibial Nerve Stimulation 173
Y. Uchikawa, T. Hasegawa, M. Kotani, K. Kida, H. Yamamoto, and H. Hosaka

Neuromagnetic Localization of Sensorimotor Cortex Sources Associated with Voluntary Movements in Humans 177
D. Cheyne, R. Kristeva, W. Lang, G. Lindinger, and L. Deecke

Measurement of Neuromagnetic Fields Preceding Triggered and Self-Paced Finger Movements 181
Y. Mizutani, K. Okano, and S. Kuriki

Neuromagnetic Localization of Late Pain-Related Fields 185
R. Wakai, J. Joseph, E. Howland, M. Backonja, F. Potenti, O. Baffa, and C. Cleeland

Multi-Dimensional Vector Analysis of Evoked Responses 189
J. Suk and D. Brenner

Neuromagnetism: Visually Evoked Responses

Identification of Multiple Sources in Transient Evoked Neuromagnetic Responses 193
C.J. Aine, J.S. George, P.A. Medvick, S. Supek, E.R. Flynn, and I. Bodis-Wollner

Spatial / Temporal Resolution of Multiple Sources: Path of Activation in Human Visual Cortex 197
J.S. George, C.J. Aine, P.A. Medvick, and E.R. Flynn

A Frequency Domain Technique for Using Evoked Magnetic Fields to Test Multi-Stage Models of Sensory Processing 201
M.P. Regan and D. Regan

Ultra-High Resolution Analysis of Auditory and Visual Brain Responses Using Zoom-FFT 205
D. Regan and M.P. Regan

Neuromagnetic Measurements of Visual Responses to Chromaticity and Luminance 209
J. Krauskopf, G. Klemic, O.V. Lounasmaa, D. Travis, L. Kaufman, and S.J. Williamson

Brain Activity Related to Spatial Visual Attention 213
B. Luber, L. Kaufman, and S.J. Williamson

Temporal Variability of the Neuromagnetic Evoked Field: Implications for Human Performance Assessment 217
G.W. Lewis, L.J. Trejo, P. Naitoh, M.H. Blankenship, and M. Inlow

Crossmodal Interactions of Auditory Stimulus Presentation on the Visual Evoked Magnetic Response 221
C. Busch, G. Wilson, C. Orr, and A. Papanicolaou

Scalp Distribution of Magnetic Fields Generated by Horizontal Eye Movements and Eye Blinks 225
M.T. Oakley, G. Sullivan, S.B.W. Roeder, and E.R. Flynn

Neuromagnetism: Spontaneous Activity and Higher Functions

A Modality-Specific Neuromagnetic P3 229
J.D. Lewine, S.B.W. Roeder, M.T. Oakley, D.L. Arthur, C.J. Aine, J.S. George, and E.R. Flynn

Cortical Resource Allocation During Mental Rotation Determined by Magneto- and Electro- Encephalography 233
G.F. Wilson, C. Busch, A. Papanicolaou, C. Oliver, and C. Orr

Alpha Suppression Related to a Cognitive Task 237
B.J. Schwartz, C. Salustri, L. Kaufman, and S.J. Williamson

Visualizing and Rhyming Cause Differences in Alpha Suppression 241
L. Kaufman, M. Glanzer, Y.M. Cycowicz, and S.J. Williamson

Phase Relationships in Synchronous Magnetic and Electric Alpha Activity in the Parieto-Occipital Area of the Human Brain 245
V.L. Vvedensky, K.G. Gurtovoy, A.P. Grebenkin, S.P. Naurzakov, V.I. Ozhogin, and S.Yu. Shabanov

Distribution of Phase for Alpha Rhythm Measured by Multichannel Magnetometer over Occipital Head 249
K.G. Gurtovoy, M.J. Kajola, and V.L. Vvedensky

Coherence Analysis of Alpha Rhythm MEG Measured Simultaneously at Two Positions 253
N. Kasai, H. Kado, M. Higuchi, M. Nakanishi, K. Chinone, and M. Koyanagi

Method for Locating Sources of Human Alpha Activity 257
S.J. Williamson, J.-Z. Wang, and R.J. Ilmoniemi

Neuromagnetic Imaging of Synchronized Mu Activity 261
L. Narici, G. Iori, I. Modena, G.L. Romani, G. Torrioli, R. Traversa, and P.M. Rossini

Sleep Spindles in Magnetoencephalography and Electroencephalography 265
N. Nakasato, K. Hatanaka, K. Seki, T. Yoshimoto, and H. Kado

Neuromagnetism: Clinical Applications and Physiology

Magnetoencephalography in Epilepsy Research and Its Perspectives (*invited*) 269
M. Balish and S. Sato

Recent Developments on the Physiological Basis of Magnetoencephalography (MEG) (*invited*) 273
Y.C. Okada

Application of a Multichannel MEG-System in Temporal Lobe Epilepsy 279
H. Stefan, S. Schneider, K. Abraham-Fuchs, J. Bauer, H. Feistel, U. Neubauer, and W.J. Huk

Mapping of MEG and EEG in Normals and Epileptic Patients 283
Yu.A. Kholodov, A.M. Gorbach, V.M. Verkhlutov, R.A. Maragey, and V.A. Konyshev

Template Analysis on Interictal Neuromagnetic Data from Cases of Focal and Generalized Epilepsy 287
G.B. Ricci, S.N. Erné, C. Del Gratta, M. Peresson, V. Pizzella, G.L. Romani, and G. Torrioli

Comparison of Dynamic Spatiotemporal Field Structures of Dorsolateral Fronto-Central Seizures and Hand Sensorimotor Cortex 291
W.W. Sutherling, C. Baumgartner, T.M. Darcey, and D.S. Barth

Pre- and Postoperative Magnetoencephalography in Partial Epilepsy. A Case Story 295
A. Sabers, J. Roenager, and the Hvidovre Epilepsy Surgery Group
K. Saermark, C.K. Bak, J. Lebech, and K.B. Mikkelsen

Multiple Source Modeling of the Human Epileptic Spike Complex in the Magnetoencephalogram 299
C. Baumgartner, W.W. Sutherling, S. Di, and D.S. Barth

A Method to Separate Contributions of Different Foci in Interictal Epileptic Activity 303
R. Stehr, Ch. Lefèbre, D. Janz, W. Scheuler, S.N. Erné, L. Trahms, and J. Wedemeyer

Ischemic and Epileptic Lesions Measured by AC- and DC-MEG 307
J. Vieth, G. Sack, P. Schueler, P. Grummich, and S. Schneider

Neuropathological Dynamics of Magnetic, Auditory Steady-State Responses in Alzheimer's Disease 311
U. Ribary, R.R. Llinás, A. Kluger, J. Suk, and S.H. Ferris

The Use of Flash and Pattern Evoked Fields in the Diagnosis of Alzheimer's Disease 315
R.A. Armstrong, B. Janday, A. Slaven, and G.F.A. Harding

Objective Evidence of Tinnitus in Auditory Evoked Magnetic Fields 319
M. Hoke, H. Feldman, C. Pantev, B. Lütkenhöner, K. Lehnertz, and W. Kumpf

Magnetic Observation of Spreading Cortical Depression in Anaesthetized Rabbits 323
A.R. Gardner-Medwin, N. Tepley, G.L. Barkley, J. Moran, S. Nagel-Leiby, R.T. Simkins, and K.M.A. Welch

Observation of Spreading Cortical Depression in Migraine Patients 327
N. Tepley, G.L. Barklay, J.E. Moran, R.T. Simkins, and K.M.A. Welch

Comparative Study of Transmembrane Potential and Magnetic Evoked Field Due to Applied Electric Field in the Turtle Cerebellum 331
L. Lopez, Y.C. Okada, C.Y. Chan, and C. Nicholson

Conductivity Boundaries May Produce Stronger Magnetic Fields than the Primary Source: Comparison of Three Analytical Methods 335
J.-C. Huang, Y.C. Okada, and C. Nicholson

In Vivo Neuromagnetic Study of Normal and Pathological Intracellular Current in Rat Cortex 339
S. Di, C. Baumgartner, W.W. Sutherling, and D.S. Barth

Cardiomagnetism: Cardiac Conduction and Physiology

Contribution Maps in Magnetocardiography (*invited*) 343
A. van Oosterom, T.F. Oostendorp, and G. Huiskamp

High Resolution Magnetocardiography, Source Localization and Multichannel Magnetometry 349
G. Albrecht, M. Burghoff, F. Gießler, W. Haberkorn, and H. Nowak

Dynamic Magnetic Study of the Heart Conduction System 353
Yu. Zhuravlev, A. Lipovich, A. Matlashov, E. Godik, and Yu. Gulyaev

Evaluation of Techniques Used to Extract His-Purkinje System Spatial Distributions 357
R. Lamothe, G. Stroink, and C.J. Kafer

Magnetocardiographic Localization of a Pacing Catheter 361
R.R. Fenici, G. Melillo, A. Cappelli, C. De Luca, and M. Masselli

Magnetocardiographic Localization of Kent Bundles 365
R.R. Fenici, G. Melillo, A. Cappelli, C. De Luca, and M. Messelli

Application of a Biomagnetic Multichannel System to the Comparative Localization of Accessory Conduction Pathways in Patients with WPW Syndrome 369
K. Abraham-Fuchs, A. Weikl, S. Schneider, W. Moshage, G. Röhrlein, A. Wirth, K. Bachmann, and R. Schittenhelm

Detection of Accessory Pathway in Patients with WPW Syndrome by Means of the Isomagnetic Map and MRI 373
M. Nomura, Y. Nakaya, K. Watanebe, M. Katayama, A. Takeuchi, K. Fujino, and H. Mori

ECG and MCG Studies on the HIS-Purkinje Activity in a Case of Congenital Heart Block 377
M. Leiniö, J. Montonen, M. Mäkijärvi, K. Mäkiniemi, J. Nenonen, T. Katila, and P. Siltanen

High-Resolution Magnetocardiographic Mapping of the Pre-Excitation in Wolff-Parkinson-White Syndrome 381
M. Mäkijärvi, J. Nenonen, M. Leiniö, J. Montonen, K. Mäkiniemi, T. Schulman, T. Katila, and P. Siltanen

Analysis of High Resolution MCG Recordings of Patients with Ventricular Tachycardia 385
J. Montonen, M. Leiniö, K. Mäkiniemi, M. Mäkijärvi, J. Nenonen, T. Katila, and P. Siltanen

Detection of Magnetic Atrial Flutter Waves in Isolated Rabbit Hearts 389
P. Costa Ribeiro, A.C. Bruno, E. Parente Ribeiro, S.J. do Carmo, E. Costa Monteiro and A. Fonseca Costa

The Magnetic Field of Isolated Rabbit Heart 393
R.S. Gonnelli, G.F. Durin, A. Sanmartino, and E. Rosettani

Cardiomagnetism: Other Clinical Applications

What Does an Electrocardiologist Expect of a Magnetocardiogram? (*invited*) 397
K. Harumi, S. Mashima, H. Tsunakawa, T. Hashimoto, K. Shimizu, and G. Nishiyama

Clinical Value of Magnetoencephalographic Mapping (*invited*) 403
Y. Nakaya, H. Mori, and M. Nomura

Biomagnetic Imaging in the Cardiac Catheterization Laboratory (*invited*) 409
R.R. Fenici and G. Melillo

Detection of the Abnormal Repolarization Vector in Diabetes Mellitus by Means of the Isomagnetic Map 417
M. Nomura, K. Watanabe, M. Katayama, A. Takeuchi, K. Fujino, Y. Nakaya, and H. Mori

Magnetocardiography in Patients with the Long QT-Syndrome 421
K. Brockmeier, L. Schmitz, L. Trahms, and S.N. Erné

Measurement of Cardiac Magnetic Field Vector 425
Y. Sakauchi, H. Kado, N. Awano, N. Kasai, M. Higuchi, K. Chinone, M. Nakanishi, K. Ohwada, and S. Kariyone

Classification of Infarcts Using Electric and Magnetic Inverse Solutions 429
C. Purcell, G. Stroink, and T.J. Montague

Descrimination Between Patients with Myocardial Infarction and Those with Ventricular Tachycardia Using Magnetic and Potential Map Extrema and Trajectory Plots 433
J. Lant, G. Stroink, D. Vardy, and M.J. Gardner

Magnetocardiographic and Electrocardiographic Recordings of Patients with Ventricular Tachycardia 437
G. Stroink, D. Vardy, R. Lamothe, and M. Gardner

Atrial and Ventricular Tachycardias: Invasive Validation and Reproducibility of Magnetocardiographic Imaging 441
R.R. Fenici, G. Melillo, A. Cappelli, C. De Luca, and M. Masselli

The Influence of Heart Motion on Magnetic Fields 445
U. Tachinardi, S.S. Furuie, S. Sirota and C.P. Melo

Effect of Constitutional Variables on Magnetocardiogram 449
J. Nousiainen, O.S. Oja, and J. Malmivuo

Magnetocardiography in Patients with Cardiomyopathy and Operated Congenital Heart Disease 453
L. Schmitz, K. Brochmeier, L. Trahms, S.N. Erné

The Magnetocardiogram in Patients with Systolic and Diastolic Overload of the Right Ventricle 457
M. Katayama, M. Nomura, K. Watanabe, A. Takeuchi, K. Fujino, Y. Nakaya, and H. Mori

Pneumomagnetism

Magnetic Microparticles can Measure Whole-Body Clearance, Cell Organelle Motions, and Protein Polymer Viscoelasticity (*invited*) 461
P.A. Valberg and K.S. Zaner

Estimation of Energy of Intracellular Movement and Apparent Viscosity by Magnetometry 469
I. Nemoto, K. Ogura, and H. Waki

Intracellular Motility of Pulmonary Macrophages from Smokers and Non-Smokers Estimated by Cytomagnetometry 473
P. Gehr, M. Klauser, and V. Im Hof

Welding Fume Retention in Lungs of Previously Unexposed Subjects 477
M. Forsman and P. Högstedt

In Vivo SQUID Measurements of the Magnetised Human Thorax 481
D. Rassi, B.H. Blott, H. Al-Sewaidan, S. Davies, and C. Ni

A Study of Magnetic Contaminants in Post Mortem Lung Samples from Asbestos Miners 485
D. Rassi, V. Timbrell, H. Al-Sewaidan, S. Davies, O. Taikina-aho, and P. Pääkkö

Effects of Latex and Different Doses of Silica on Behavior of Iron Particles in Rabbit Lungs 489
Y. Aizawa, T. Takata, K. Hashimoto, M. Tominaga, H. Tatsumi, M. Kotani, and K. Chiyotani

Research on Biomagnetic Technique Used for Tracing Pneumoconiosis of Metallurgical Workers 493
B. Yu, K. Xiang, P. Hu, L. Li

Tissue Susceptiblity

The Hamburg Biosusceptometer for Liver Iron Quantification 497
D.N. Paulson, R. Engelhardt, R. Fischer, and H.C. Heinrich

The Calibration Problem in Liver Iron Susceptometry 501
R. Fischer, E. Eich, R. Engelhardt, H.C. Heinrich, M. Kessler, and P. Nielsen

Magnetic Mapping of DC Fields Related to Tissue Susceptibility in the Human Body 505
S. Di Luzio, G. Obletter, S. Comani, C. Del Gratta, and G.L. Romani

Diverse Applications

Ionic Currents Within Developing Chick Eggs 509
S.M. Freake, B.S. Janday, S.J. Swithenby, and I.M. Thomas

Magnetic Field Measurements of the Electric Organ of Gymnotus Carapó 513
O. Baffa, S. Lopes Côrrea, C.A. Pelá, and A. Tannus

Measurement of Magnetic Field Near An Acute Surgical Injury on the Rabbit's Thigh 517
Z. Trontelj, J. Pirnat, J. Lužnik, V. Jazbinšek, V. Valenčič, D. Križaj, L. Vodovnik, and A. Jerčinović

Biochemical Magnetite Formation and Its Application 521
T. Hamaya and K. Horikoshi

Immunosensor Using Bacterial Magnetites 525
N. Nakamura and T. Matsunaga

Localized Stimulation of the Human Cortex by Opposing Magnetic Fields 529
S. Ueno, T. Matsuda, and M. Fujiki

Modeling, Theory, and Data Processing

Volume Current Effects on MEG and Modeling (*invited*) 533
E. Ducla-Soares

Impact of Different Noise Sources on Dipole Localization in the Spherical Model: A Simulation 539
D.S. Buchanan

Monte Carlo Analysis of Localization Errors in Magnetoencephalography 543
P.A. Medvick, P.S. Lewis, C. Aine, and E.R. Flynn

A Variation Principle for the Return Current in Encephalography 547
L. Heller

Magnetoencephalographic Localization of Simulated Evoked Response Sources Affirms the Importance of Adequate Modeling 551
P.J. DeRego and A.F. Badeau

Improved Methods for MEG Inverse Dipole Estimation 555
L. Goldstein, P. Teale, and M. Reite

Influence of the Finite Pickup Coil Size on the Location of Current Sources with Quadrupolar Components 559
V. Jazbinšek, Z. Trontelj, S.N. Erné, and L. Trahms

Considerations on a Spatio-Temporal Two-Dipole Model 563
K. Lehnertz, B. Lütkenhöner, M. Hoke, and C. Pantev

Rule-Based Location of Multiple Current-Dipole Sources from Biomagnetic Data 567
N.M. Palfreyman, K.D. Singh, and S.J. Swithenby

A Linear Estimation Approach to Biomagnetic Imaging 571
W.H. Kullmann, K.D. Jandt, K. Rehm, H.A. Schlitt, W.J. Dallas, and W.E. Smith

Discussion of Biomagnetic Imaging System and Reconstruction Algorithm 575
H. Haneishi, N. Ohyama, and K. Sekihara

Direct Approach to an Inverse Problem: A Trial to Describe Signal Sources by Current Elements Distribution 579
H. Kado, S. Kashiwaya, M. Higuchi, and H. Miura

Magnetic Fields of Current Monopoles 583
A.S. Ferguson and D. Durand

Localised and Distributed Source Solutions for the Biomagnetic Inverse Problem, I 587
C.J.S. Clarke, A.A. Ioannides, and J.P.R. Bolton

Localised and Distributed Source Solutions for the Biomagnetic Inverse Problem, II 591
A.A. Ioannides, J.P.R. Bolton, R. Hasson, and C.J.S. Clarke

Random Dipoles as a Model for Spontaneous EEG and MEG Activity 595
J.C. De Munck, P.C.M. Vijn, and H. Spekreijse

Theory and Properties of Lead Field Synthesis Analysis 599
S.E. Robinson

Minimum Norm Estimation of Current Distributions in Realistic Geometries 603
C.W. Crowley, R.E. Greenblatt and I. Khalil

Localizing Abnormalities in Mapping 607
S.S. Furuie, U. Tachinardi, S. Sirota, and C.P. Melo

Preliminary Tests of MEG and EEG Localization in a Homogeneous Saline Head 611
R. Maniewski, D. Cohen, B.N. Cuffin, K. Yunokuchi, and C. Purcell

Projective Methods for the Magnetic Direct Problem 615
S.L. Gonzalez, R. Grave de Peralta, R. Biscay, J.C. Jimenez, R.D. Pascual, J. Lemagne, and P.A. Valdes

Mechanism of Flux Reversal Phenomena in Spatial Distributions of the Magnetoencephalograms 619
K. Iramina and S. Ueno

Constructing a Realistically Shaped Model of the Human Head 623
V.A. Konyshev, R.A. Maragey, Yu.A. Kholodov, V.M. Verkhlutov, and A.M. Gorbach

Compression of Biomagnetic Data by Combining Linear Predictive and Variable-Length Coding 627
B. Lütkenhöner, C. Pantev, M. Hoke, and K. Lehnertz

Interactive Control and Data Processing in Multichannel SQUID Instrumentation Systems 631
J.H. Voskamp, R. Niessen, A.J. van der Wal

Channel Capacity of Multichnnel Magnetometers 635
P.K. Kemppainen and R.J. Ilmoniemi

Instrumentation

A 24-Channel Planar Gradiometer: System Design and Analysis of Neuromagnetic Data (*invited*) 639
M.S. Hämäläinen

Improved SQUID Magnetometer with an External Feedback Circuit 645
Y. Igarashi, T. Goto, T. Hayashi, N. Fujimaki, K. Kawabe, T. Shimura, and H. Hayashi"

Designing Planar Gradiometer Arrays: Preliminary Considerations 649
A.C. Bruno and P. Costa Ribeiro

Pb-In Wire Bonding for Superconducting Connection between Thin Film DC-SQUID and Pickup Coil 653
S. Kiryu, T. Ogashiwa, K. Chinone, N. Kasai, H. Kado, N. Ishikawa, M. Nakanishi, and M. Koyanagi

A Single-Chip SQUID 657
N. Fujimaki, H. Tamura, H. Suzuki, T. Imamura, S. Hasuo, and A. Shibatomi

A Multi-Channel Biomagnetometer 661
C.N. Guy, A. Cayless, S. Walker, and K. Leedham-Green

A Nine Channel DC SQUID System for Biomagnetism 665
P. Carreli, C. Del Gratta, V. Foglietti, I. Modena, A. Pasquarelli, V. Pizzella, M. Pullano, G.L. Romani, and G. Torrioli

Development and Performance of a Multichannel System for Studies of Biomagnetic Signals of Brain and Heart 669
S. Schneider, K. Abraham-Fuchs, G. Daalmans, W. Folberth, H.E. Hoenig, H. Reichenberger, G. Röhrlein, H. Seifert, and A. Wirth

A 24-Channel Magnetometer for Brain Research 673
M. Kajola, S. Ahlfors, G.J. Ehnholm, J. Hällström, M.S. Hämäläinen, R.J. Ilmoniemi, M. Kiviranta, J. Knuutila, O.V. Lounasmaa, C.D. Tesche, and V. Vilkman

MicroSQUID: A Close-Spaced Four Channel Magnetometer 677
D.S. Buchanan, D.B. Crum, D. Cox, and J.P. Wikswo

Preliminary Measurements with MicroSQUID 681
J.P. Wikswo, R.N. Friedman, A.W. Kilroy, J.M. van Egeraat, and D.S. Buchanan

Sequential Spatially Distributed Activity of the Human Brain Detected Magnetically by CryoSQUIDs 685
G.A. Klemic, D.S. Buchanan, Y.M. Cycowicz, and S.J. Williamson

Techniques and Methodology

The LANL Gradiometer Orientation Device 689
D.B. van Hulsteyn, L. McGavran, L. Heller, J. George, P. Medvick, and E. Flynn

Magnetometer Position Indicator for Multichannel MEG 693
S. Ahlfors and R.J. Ilmoniemi

Subject and Gradiometer Positioning for MEG Recording: A Preliminary Report 697
P. Teale, J.E. Zimmerman, J. Edrich, S. Linnville, and M. Reite

The Positioning of Magnetometer Pickup Coil in Dewar by Artificial Signal Source 701
M. Higuchi, K. Chinone, N. Ishikawa, H. Kado, N. Kasai, M. Nakanishi, M. Koyanagi, and Y. Ishibashi

Neuromagnetometer® Calibration Using an Array of Small Coils 705
D.S. Buchanan and D.N. Paulson

Spatial Fourier Technique for Calibrating Gradiometers 709
A.C. Bruno, C.S. Dolce, S.D. Soares, amd P. Costa Ribeiro

On the Spatial Locating Accuracy of Multichannel Magnetometers 713
J. Knuutila and M.S. Hämäläinen

Experimental Accuracy of Localization of Current Dipoles in a Spherical Phantom 717
D.N. Paulson and D.S.Buchanan

Environmental Noise Cancellation for Biomagnetic Measurements 721
S.E. Robinson

Electronic Noise Suppression in Multichannel Neuromagnetic System 725
A. Matlashov, Yu. Zhuravlev, A. Lipovich, A. Alexandrov, E. Mazaev, V. Slobodchikov, and O. Wazhiewski

Thermal Noise of a Biomagnetic Measurement Dewar 729
J. Nenonen, T. Katila, and J. Montonen

Noise Cancellation in Biomagnetometers 733
J. Vrba, J. McCubbin, S. Lee, A.A. Fife, and M.B. Burbank

Three-Dimensional Volumetric Reconstruction for Neuromagnetic Source Localization 737
J.S. George, P.S. Jackson, D.M. Rankin, and E.R. Flynn

An Integrated Stimulus Generation and Data Acquisition System for the Investigation of Auditory Evoked Magnetic Fields 741
E. Ross, B. Lütkenhöner, M. Hoke, and C. Pantev

Study on a Design Method of a Magnetically Shielded Room by Using Models 745
K. Yamazaki, K. Unno, and K. Seino

Preparation of High-T_c Superconducting Magnetic Shields by a Low Pressure Plasma Spraying 749
K. Tachikawa, O. Tsukamoto, Y. Shimbo, K. Niki, M. Ono, M. Kabasawa, and S. Kosuge

Author Index 753

Subject Index 759